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QUALITY EVALUATION OF SASKATCHEWAN LIGNITE RESOURCES PHYSICAL AND CHEMICAL ANALYSES

T.E. TIBBETTS

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QUALITY EVALUATION OF SASKATCHEWAN LIGNITE RESOURCES
PHYSICAL AND CHEMICAL ANALYSES

BY

T.E. TIBBETTS*

ABSTRACT

SINCE 1972 CANADA AND THE PROVINCE OF SASKATCHEWAN HAVE BEEN CO-OPERATING IN A JOINTLY FINANCED PROGRAM DESIGNED TO EVALUATE THE LIGNITE RESOURCES IN THE RAVENSCRAG FORMATION OF SOUTHERN SASKATCHEWAN.

IN 1972 AND 1973 A TWO-PHASED DRILLING PROGRAM WAS CONDUCTED IN THE FOUR MAJOR COAL AREAS, ESTEVAN, WILLOW BUNCH, WOOD MOUNTAIN AND SHAUNAVON. DURING THIS PROGRAM MORE THAN 700 BORE HOLES WERE DRILLED AND MORE THAN 6,000 COAL SAMPLES OBTAINED.

THE AUTHOR OUTLINES THE PROCEDURES FOLLOWED TO EVALUATE THE PHYSICAL AND CHEMICAL PROPERTIES AND TO RECORD FOR SUBSEQUENT ELECTRONIC PROCESSING THE DATA RESULTING FROM THE ANALYSES OF ABOUT 4,900 SAMPLES CARRIED OUT BY THE DEPARTMENT OF ENERGY, MINES AND RESOURCES.

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*PROJECT LEADER, NATIONAL ENERGY RESEARCH PROGRAM, CANADA CENTRE FOR MINERAL AND ENERGY TECHNOLOGY, DEPARTMENT OF ENERGY, MINES AND RESOURCES, OTTAWA.

INTRODUCTION

Since 1913[1] when Dowling prepared the first estimate of coal resources in Canada, the estimate has declined significantly with each succeeding study. In 1970 Latour and Chrismas[2] made the first tabulation of measured coal resources in British Columbia, Alberta and Saskatchewan together with a reassessment of the probable and possible resources that were estimated by McKay in 1946[3]. That study originated as part of a preliminary investigation by Canada to determine the Country's total energy resources comprising coal, petroleum, natural gas, uranium and water.

In 1970, Latour and Chrismas estimated that the coal resources in Saskatchewan amounted to about 12 billion tons. For the most part this coal, all of lignite rank, was part of the Ravenscrag Formation of southern Saskatchewan.

In 1972 an agreement was made between Canada and the Province of Saskatchewan providing for not only a quantitative but also a qualitative evaluation of the coal deposits of the Ravenscrag Formation. This coal bearing formation occurs as a band of sediments varying in thickness to 1200 feet covering areas known as Estevan, Willow Bunch, Wood Mountain and Shaunavon (Cypress). Only in immediate areas of Estevan had sufficient drilling been done to determine the reserves.

In November 1974 preliminary estimates of the lignite resources located at a maximum depth of 150 feet were reported from this on-going study as follows:

SASKATCHEWAN LIGNITE RESOURCES EVALUATION

AREA	BILLIONS OF SHORT TONS
ESTEVAN	1.08
WILLOW BUNCH	2.85
WOOD MOUNTAIN	1.01
SHAUNAVON (CYPRESS)	0.73
TOTAL SASKATCHEWAN	5.67

A MORE COMPLETE ASSESSMENT OF THE TOTAL RESOURCES WILL BE REPORTED IN 1975.

THESE FIGURES ARE BASED ON THE RESULTS FROM THE TWO-YEAR BOREHOLE DRILLING PROGRAM DURING 1972 AND 1973 IN WHICH APPROXIMATELY 700 BOREHOLES WERE DRILLED. TOGETHER WITH INFORMATION FROM AN ADDITIONAL 500 BOREHOLES OF RELATED PROVINCIAL COAL EVALUATION PROGRAMS A DENSITY OF CONTROL RANGING FROM ½ MILE TO 2 MILE CENTERS WAS PROVIDED. INCLUDED IN THE PRELIMINARY RESERVE CALCULATIONS WERE ALL COAL SEAMS THAT ARE AT LEAST 5 FEET THICK AND WITHIN 150 FEET OF SURFACE OR 3 TO 5 FEET THICK PROVIDED THE OVERBURDEN/SEAM RATIO IS LESS THAN OR EQUAL TO 15 LINEAR FEET OF OVERBURDEN TO ONE LINEAR FOOT OF COAL. SEAM PARTINGS OF CLASTIC MATERIAL AND COAL LESS THAN ONE FOOT THICK WITHIN A SEAM ARE NOT INCLUDED IN THE RESERVES.

ALTHOUGH SOME PREVIOUSLY UNKNOWN DEPOSITS OF LIGNITE WERE DISCOVERED DURING THIS PROGRAM, INDICATIONS ARE THAT ESTIMATES OF TOTAL RESERVES WILL BE SUBSTANTIALLY REDUCED RELATIVE TO THOSE ESTIMATES PREVIOUSLY PUBLISHED.

THIS IS THE FIRST ASSESSMENT OF THE LIGNITE RESOURCES THAT INCLUDES A DETAILED STUDY OF THE QUALITY OF THE LIGNITE OF THE RAVENSCRAG FORMATION. PREVIOUS STUDIES HAVE DONE LITTLE MORE THAN DETERMINE THE RANK OF THE COAL AND PRESENT WHAT WAS CONSIDERED A TYPICAL ANALYSIS.

THE PURPOSE OF THIS PAPER IS TO PRESENT A GENERAL OUTLINE OF THE MANNER IN WHICH THE QUALITY ASSESSMENT WAS CONDUCTED AND GIVE PRELIMINARY EVALUATIONS OF THE LIGNITE AS REPRESENTED BY A VERY EXTENSIVE BOREHOLE SAMPLING PROGRAM.

PROCEDURES - SAMPLING

IN THIS PROGRAM SAMPLES OF COAL WERE RECOVERED FROM THE BOREHOLES BY THREE METHODS: (A) NORMAL ROTARY DRILLING, (B) REVERSE CIRCULATION DRILLING WITH DUAL-WALL PIPE, AND (C) CONTINUOUS ROTARY CORE DRILLING.

IN THE FALL OF 1972 AND THE SPRING OF 1973 THE RELIABILITY OF THESE SAMPLING METHODS WAS TESTED. THE DETAILS OF THE TESTS INVOLVED HAVE BEEN REPORTED EARLIER[5] AND ARE ONLY BRIEFLY DESCRIBED HERE.

NORMAL ROTARY DRILLING EMPLOYS SINGLE-WALL PIPE, AND AS THE DRILL BIT IS ROTATED, WATER OR DRILLING MUD IS PUMPED DOWN THE INSIDE OF THE PIPE AND CARRIES THE DRILL CUTTINGS WITH IT AS IT RETURNS TO THE SURFACE IN THE SPACE BETWEEN THE PIPE AND THE BOREHOLE. THE LIKELIHOOD OF SIDE WALL MATERIAL INCLUSIONS IS THEREFORE HIGH. ROTARY CORE DRILLING EMPLOYS A CORE BARREL ATTACHED TO THE END OF THE DRILL STEM TO RECEIVE THE INTERSECTION.

REVERSE CIRCULATION DRILLING WITH DUAL-WALL PIPE INVOLVES PUMPING OF FLUID DOWN THE SPACE BETWEEN THE INNER AND OUTER PIPE AND RETURN, CARRYING THE DRILL CUTTINGS, UP THE CENTRE. THE CIRCULATING FLUID IS USUALLY AIR WITH A SMALL AMOUNT OF ADDED WATER TO ENSURE LUBRICATION OF CUTTINGS. CUTTINGS COMING TO THE SURFACE AT HIGH SPEED ARE DECELERATED AND COLLECTED AS UNDERFLOW FROM A CYCLONE.

TWO BOREHOLES, A AND B, WERE SAMPLED AT THE SITE BY EACH OF THE DRILL SAMPLING METHODS. IN ADDITION, CROSS-SECTION SAMPLES WERE TAKEN IN THE PRODUCTION SEAM NEARBY THE SITE OF THE DRILLING TESTS.

THE TEST INDICATED QUITE CONCLUSIVELY THAT SAMPLES FROM REGULAR ROTARY DRILLING WERE NOT SUFFICIENTLY RELIABLE BY THEMSELVES TO REPRESENT THE COAL INTERSECTIONS AS THE ASH CONTENTS WERE SIGNIFICANTLY HIGHER THAN THOSE OF THE SAMPLES COLLECTED BY THE OTHER METHODS. ON THE OTHER HAND, THE ASH CONTENTS OF THE SEAM AS REPRESENTED BY THE REVERSE CIRCULATION SAMPLES AGREED VERY WELL WITH THE ASH CONTENTS AS REPRESENTED BY THE ROTARY DRILL CORE AND THE CROSS-SECTION SAMPLES. FOR ALL METHODS THE REPEATABILITY OF SAMPLING OF THE COMPLETE SEAM INTERSECTION WAS HIGH. THE ROTARY DRILL SAMPLING YIELDED GREAT VARIANCE IN THE ASH CONTENTS OF CORRESPONDING FOOTAGE INTERVALS.

THE RESULTS OF THE TESTS REPRESENTED BY THE ASH CONTENTS AT TEST SITE ESTEVAN 76 ARE SUMMARIZED BELOW.

SASKATCHEWAN LIGNITE RESOURCES EVALUATION

Sampling Method	1-foot Intervals Mean Difference (A and B)	Seam Composite A	Seam Composite B
Rotary Drill	11.8	25.3	26.4
Reverse Drill	5.0	15.5	13.9
Core Drill	5.8	15.5	15.6
Cross Section	2.1	12.0	12.7

The seam average ash contents of the rotary drill samples were so high compared to those recovered by the other methods that this method was judged unreliable for lignite resource quality evaluation.

Subsequent visual examination of samples from the numerous boreholes drilled under this project indicated the presence of contaminating uphole sand and clays and confirmed the conclusions of unreliability of the sampling method. It was therefore decided that lignite samples collected by the regular rotary drilling method would not be useful in evaluating the overall quality of the lignite resources. Analyses of the rotary samples was justified as the analyses on the pure coal basis would be valid for purposes such as seam correlations and rank determinations.

PROCEDURES - ANALYSIS

THE TWO-PHASED DRILLING PROGRAM RESULTED IN THE COLLECTION OF MORE THAN 6,000 SAMPLES AT, FOR THE MOST PART, 1-FOOT INTERVALS IN INTERSECTIONS OF COAL SEAMS FROM 711 BOREHOLES. AT SOME OF THE SITES WHERE UNIFORMITY OF COAL QUALITY AND UNINTERRUPTED SEAMS WERE INDICATED BY THE LITHOLOGICAL INFORMATION THE ONE-FOOT INTERVAL SAMPLES WERE COMPOSITED IN RELATIONSHIP TO THE SEAM THICKNESS. THIS RESULTED IN REDUCTION OF THE NUMBER OF SAMPLES FOR ANALYSIS TO ABOUT 4,900.

THE NUMBER OF SAMPLES SUBMITTED FOR ANALYSIS FROM EACH OF THE FOUR AREAS COMPRISING THE SOUTHERN SASKATCHEWAN COAL FIELDS, AND THE SAMPLING METHOD ARE SUMMARIZED BELOW:

SASKATCHEWAN LIGNITE RESOURCES EVALUATION

AREA	METHOD OF SAMPLING			TOTAL
	ROTARY DRILL	REVERSE DRILL	CORE AND CROSS SECTION	
ESTEVAN	871	322	93	1,286
WILLOW BUNCH	1,306	602	35	1,943
WOOD MOUNTAIN	852	353	-	1,205
SHAUNAVON (CYPRESS) ...	229	220	21	470
TOTAL SASKATCHEWAN ..	3,258	1,497	149	4,904

Of the total samples analysed, 30.5 percent were collected by the reverse circulation drilling method. Using the preliminary estimates of reserves submitted in November 1974 and referred to above the area distribution of samples by reverse circulation is in the relative order of the resource distribution as shown below:

SASKATCHEWAN LIGNITE RESOURCES EVALUATION

Area	Estimated Resources Percentage of Total	Reverse Samples Percentage Representation
ESTEVAN	19.0	26.2
WILLOW BUNCH	50.3	39.6
WOOD MOUNTAIN	17.8	24.6
SHAUNAVON (CYPRESS) ...	12.9	9.6

The samples were contained in plastic bags, properly identified and sealed, and shipped to the Energy Research Laboratories, Department of Energy, Mines and Resources, Ottawa.

At the laboratory, following identification, the samples were entered into the project sample index control system and the laboratory sequential indexing system. Figures 1 and 2 are flow diagrams for the normal sequence of sample preparation and analysis.

The weight of the samples varied from about 3 to 10 pounds and the particle size up to about 2½ inches. Precautions were taken to minimize loss of moisture during the removal of a 50-gram subsample from the main sample prior to further sample preparation. The 50 gram subsample was sealed in a plastic envelope to await determination of the equilibrium or inherent moisture.

The main sample was dried in an oven at 32C. After drying, this sample was crushed and pulverized to pass a No. 60 sieve in a Holmes pulverizer and identified as the analytical sample.

ASTM Standard Test procedures were as follows[6]:

Saskatchewan Lignite Resources Evaluation

Analysis Procedures

1. Moisture ..... ASTM D-3173
2. Ash ..... ASTM D-3174
3. Volatile Matter ..... ASTM D-3175
4. Sulphur ..... ASTM D-3177
5. Calorific Value ..... ASTM D-2015
6. Equilibrium Moisture ..... ASTM D-1412
7. True Specific Gravity .... ASTM D-167

THE ANALYTICAL PROCEDURES FOR MOISTURE, ASH, VOLATILE MATTER, SULPHUR AND CALORIFIC VALUE DETERMINATIONS WERE CONDUCTED ON ALL SAMPLES. FOR SOME SAMPLES, SPECIFICALLY THOSE ROTARY DRILL SAMPLES CONTAMINATED BY CLAY, THE EQUILIBRIUM MOISTURE AND SPECIFIC GRAVITY WERE ESTIMATED FOLLOWING PROCEDURES OUTLINED BELOW.

THEORETICALLY, INHERENT MOISTURE IS THE MOISTURE THAT A COAL CAN HOLD WHEN IN EQUILIBRIUM WITH AN ATMOSPHERE OF 100 PER CENT RELATIVE HUMIDITY. ACTUALLY, IT IS DETERMINED AT 95 TO 97 PER CENT RELATIVE HUMIDITY DUE TO PHYSICAL DIFFICULTIES IN TRYING TO MAKE DETERMINATIONS AT 100 PER CENT RELATIVE HUMIDITY. THE EQUILIBRIUM MOISTURE IS THEORETICALLY THE INHERENT MOISTURE OF THE COAL AS IT OCCURS IN THE UNEXPOSED SEAM BECAUSE THE RELATIVE HUMIDITY IN THE IMMEDIATE VICINITY IS PROBABLY AT OR NEAR 100 PER CENT. IT IS THEREFORE MOST USEFUL IN EVALUATING IN SITU RESOURCES OF HIGH MOISTURE COALS.

WHEN THERE WAS A PRESENCE OF LARGE QUANTITIES OF MINERAL MATTER, PARTICULARLY CLAY, IN THE SAMPLES IT WAS IMPOSSIBLE BY USING THE STANDARD METHOD TO ACCURATELY DETERMINE THE EQUILIBRIUM MOISTURE. AS MENTIONED ABOVE, THE FREQUENCY OF SUCH OCCURRENCES WAS HIGH FOR THE ROTARY DRILL SAMPLES. THE RESULTS OF ANALYSES OF REVERSE CIRCULATION DRILL SAMPLES FROM THE WILLOW BUNCH AREA CONTAINING UP TO 50 PERCENT ASH WERE PLOTTED WITH THE CORRESPONDING ASH CONTENT. THE RESULT WAS AN ALMOST LINEAR SCATTER. FOR THE PURPOSE OF ESTIMATING THE EQUILIBRIUM MOISTURE OF HIGH ASH ROTARY DRILL SAMPLES WHEN THE ASH WAS SUSPECTED TO BE LARGELY DUE TO THE PRESENCE OF CLAYS A STRAIGHTLINE RELATIONSHIP WAS EVOLVED. THIS RELATIONSHIP INVOLVED THE ASSUMPTION OF EQUILIBRIUM MOISTURE VALUES FOR MINERAL-MATTER FREE COAL AND FOR MINERAL MATTER. THESE ASSUMED VALUES WERE 36 PER CENT AND 0 RESPECTIVELY.'

THE ESTIMATED VALUES FOR THE HIGH ASH ROTARY DRILL SAMPLES ARE BELIEVED TO BE VALID FOR THE PURPOSE OF CALCULATING THE MOIST MINERAL-MATTER-FREE CALORIFIC VALUES USED FOR RANK CLASSIFICATION. FROM THE GRAPH OF THE RELATIONSHIP OF THE EQUILIBRIUM MOISTURE AND THE ASH CONTENT A SERIES OF TABLES WERE PREPARED FROM WHICH AN ESTIMATED EQUILIBRIUM MOISTURE COULD BE OBTAINED FROM ANY MEASURED ASH CONTENT OF THE LIGNITE FROM 15.0 PER CENT TO 70.0 PER CENT.

ACTUALLY, THE ASTM STANDARD TEST FOR DETERMINATION OF SPECIFIC GRAVITY, D-167 SPECIFICALLY APPLIES TO COKE. THE METHOD WAS MODIFIED FOR LIGNITE AND IS REFERRED TO AS THE HOGARTH DENSITY. THE MODIFIED METHOD UTILIZED THE NORMAL ANALYTICAL SAMPLE. DUE TO THE NATURE OF THE TEST THE HIGH CLAY CONTENT OF SOME OF THE ROTARY DRILL SAMPLES PREVENTED ACCURATE DETERMINATION OF THE SPECIFIC GRAVITY OF THOSE SAMPLES. TESTING REVERSE CIRCULATION DRILL SAMPLES YIELDED SPECIFIC GRAVITY DATA THAT, WHEN PLOTTED WITH THE CORRESPONDING ASH CONTENT, PRODUCED AN ALMOST LINEAR SCATTER. FOR THE PURPOSE OF ESTIMATING THE SPECIFIC GRAVITY OF THE HIGH ASH ROTARY DRILL SAMPLES WHEN THE ASH WAS SUSPECTED TO BE LARGELY DUE TO THE PRESENCE OF CLAY A STRAIGHT LINE RELATIONSHIP WAS EVOLVED. AS FOR THE RELATIONSHIP DETERMINED FOR THE EQUILIBRIUM MOISTURE AND ASH CONTENT, AN ASSUMPTION WAS INVOLVED WITH RESPECT TO THE DENSITIES OF THE MINERAL MATTER AND THE LIGNITE. THE ASSUMED VALUES FOR THE MINERAL MATTER AND THE MINERAL-MATTER-FREE LIGNITE WERE 2.6 AND 1.45, RESPECTIVELY. AS FOR THE ESTIMATES OF THE EQUILIBRIUM MOISTURE, A SERIES OF TABLES WERE PREPARED FROM WHICH ESTIMATES OF THE DENSITIES OF LIGNITE OF ASH CONTENTS FROM 15.0 TO 76.0 COULD BE READ.

Because of the large number of samples associated with this program, time and staff and financial resources did not permit such tests as grindability index, ash analysis (constituents of ash), ash fusion and ultimate analysis (carbon, hydrogen and nitrogen). It is planned to proceed with such work if and when these shortcomings are overcome.

DATA HANDLING AND SUMMARY OF ANALYSIS

Coal chemistry coding forms, to be described in a separate paper, were specifically designed for this project. These forms were used to record the analytical data. They were designed as a basic step to allow electronic recording, verification and processing of lignite quality data. This processing, to be described in the next paper, will permit a "marriage" of the coal chemistry and geology of the Ravenscrag formation to form a qualitative and quantitative assessment of the lignite resources of Saskatchewan.

The completion progress of the coal chemistry was recorded as the analyses of samples from each site was completed and coded. This phase of the program was compete as of April 30, 1975.

The basic analytical data as recorded in the Coal Chemistry Coding Forms were transmitted to the Saskatchewan Research Council where an electronic data processing program, financed by the Department of Energy, Mines and Resources, has been developed and used to establish a coal chemistry tape file.

THE CHEMISTRY DATA FROM THE REVERSE CIRCULATION DRILL SAMPLES INDICATE SOME FAIRLY DEFINITE TRENDS IN A SITE BY SITE ANALYSIS OF THE COAL FIELD. GOING FROM EAST (ESTEVAN) TO WEST (CYPRESS), THE FOLLOWING OBSERVATIONS WERE MADE:

SASKATCHEWAN LIGNITE RESOURCES EVALUATION

1. THE ASH CONTENT INCREASES
2. THE CALORIFIC VALUE DECREASES
3. THE EQUILIBRIUM MOISTURE DECREASES
4. THE SPECIFIC GRAVITY INCREASES

FURTHER DATA PROCESSING IS REQUIRED TO DETERMINE THE VALIDITY OF THESE OBSERVATIONS IN TERMS OF RESOURCE PARAMETERS. THE PRESENT INDICATED TRENDS ARE BASED ON RAW DATA. THE RAW DATA, FOR EXAMPLE DRY DENSITY, WILL BE CONVERTED TO "IN SITU" DATA ON THE EQUILIBRIUM MOISTURE BASIS BY MEANS OF AVAILABLE TRANSFORMS[7] OR FORMULAE TO BE INSERTED IN THE COMPUTER PROGRAM.

THE FOLLOWING TABLE PRESENTS A SUMMARY OF THE ANALYSES OF 1,252 REVERSE CIRCULATION SAMPLES FROM A TOTAL OF 129 SITES FOR WHICH DATA HAS BEEN VERIFIED.

SASKATCHEWAN LIGNITE RESOURCES EVALUATION

SUMMARY OF ANALYSES

Area	Dry Ash, %		Equil. Moist.%		Dry Density		Dry BTU/LB	
	Mean	σ	Mean	σ	Mean	σ	Mean	σ
Estevan	25.03	8.53	26.99	3.28	1.70	0.10	8816	1097
Willow Bunch	29.76	10.95	25.39	3.81	1.79	0.14	7815	1507
Wood Mountain	38.06	8.54	23.34	2.91	1.88	0.10	6887	1249
Shaunavon (Cypress)	44.73	14.88	24.29	6.11	1.93	0.21	6738	1978
Total Saskatchewan	31.94	10.61	25.33	3.85	1.80	0.13	7768	1440

Below is what might be considered a typical analysis of a lignite from Estevan delivered to a Saskatchewan power plant.

Analysis of Commercial Lignite[8]

(Delivered to Thermal Power Plant)

Proximate Analysis		
Moisture	%	28.6
Ash	%	11.4
Volatile Matter	%	27.5
Fixed Carbon	%	32.5
Sulphur	%	0.2
Calorific Value	Btu/lb.	7280
Ash Fusibility		
Initial Temp.	°F	2000
Softening Temp: (a) Spherical	°F	2060
(b) Hemispherical	°F	2280
Fluid Temp.	°F	2460
Grindability Index (Hardgrove)		49
Classification by Rank (ASTM)		Lignite A

COST OF ANALYSES

USING THE CANMET GUIDELINES FOR THE COST RECOVERY FOR CONDUCTING INVESTIGATIONS, "SCHEDULE OF FEES FOR TESTS AND ANALYSES",(9) THE OVERALL ANALYTICAL COST OF THIS PROGRAM WAS $358,230, OR AN AVERAGE COST OF $73.05 PER SAMPLE. THESE COSTS WERE FULLY BORNE BY CANMET.

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SASKATCHEWAN LIGNITE RESOURCES EVALUATION

FIGURE 1. FLOW DIAGRAM FOR SAMPLE PREPARATION

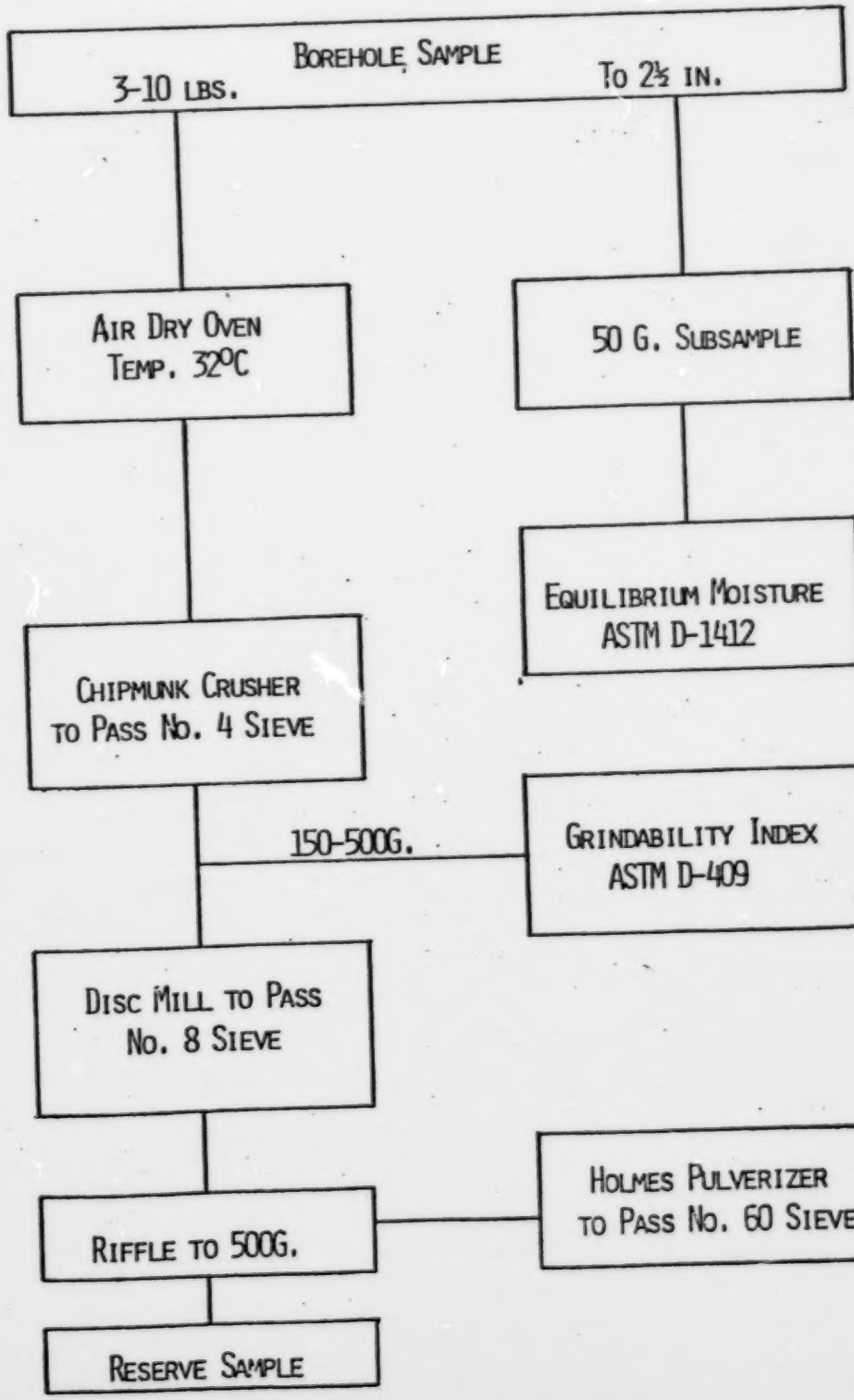
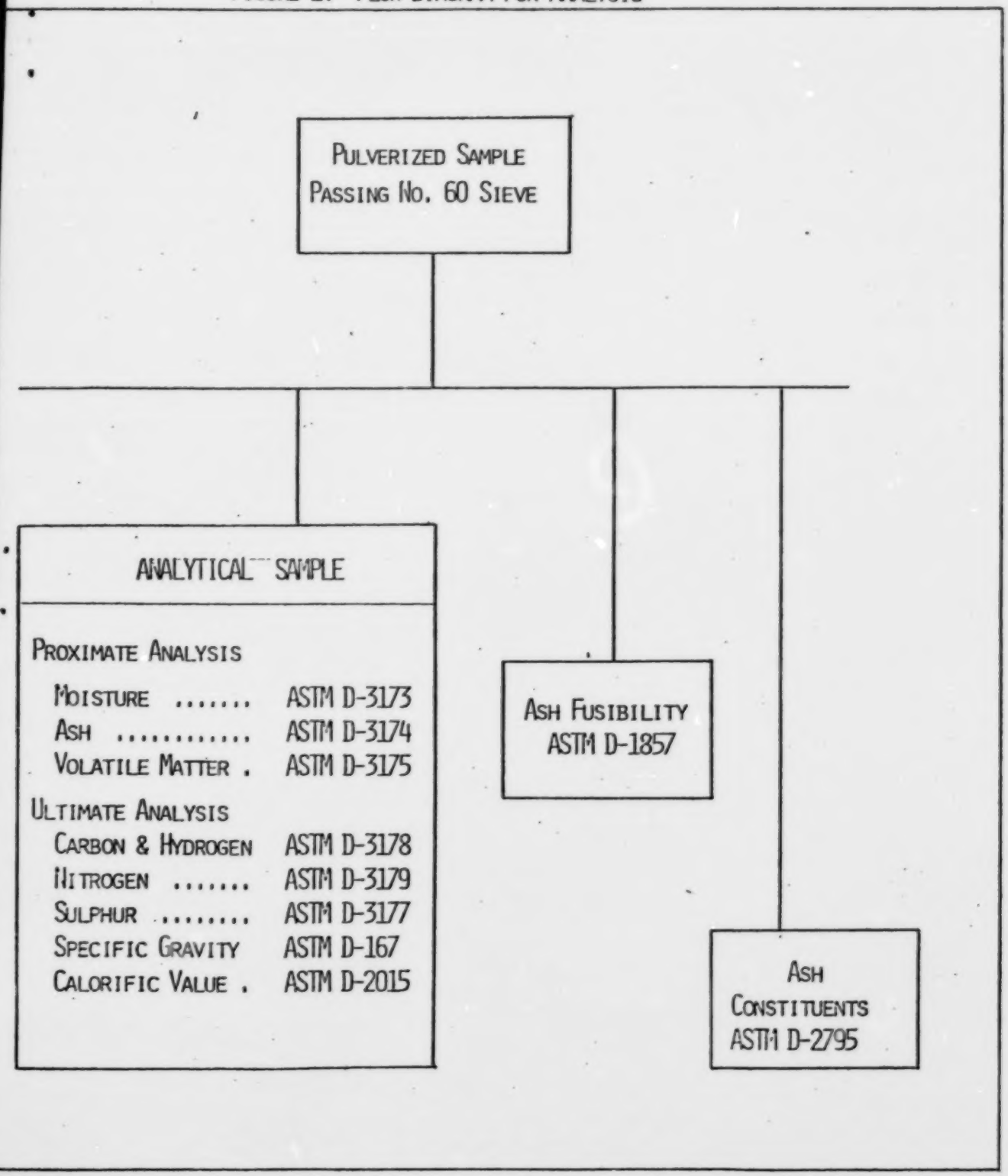
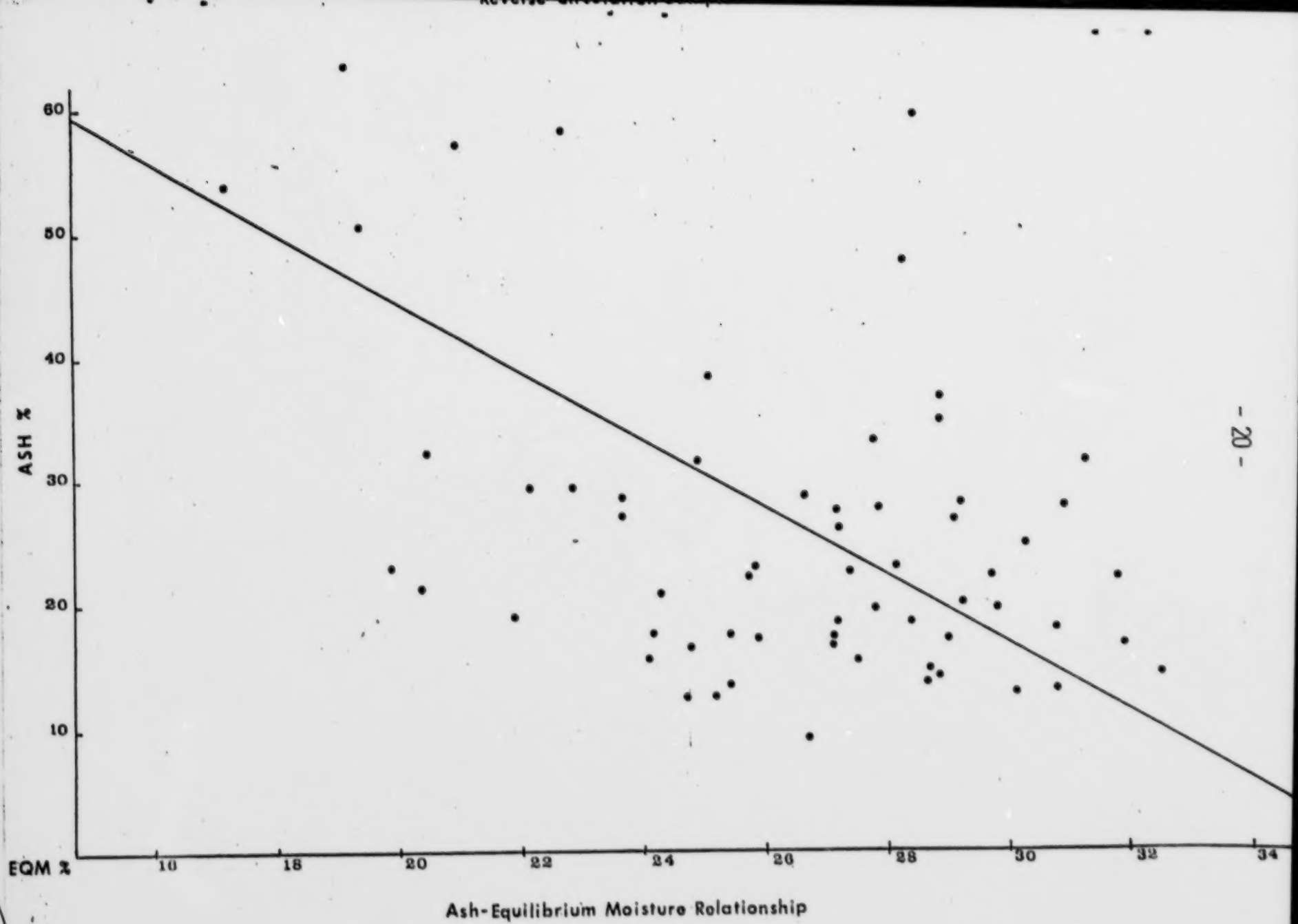
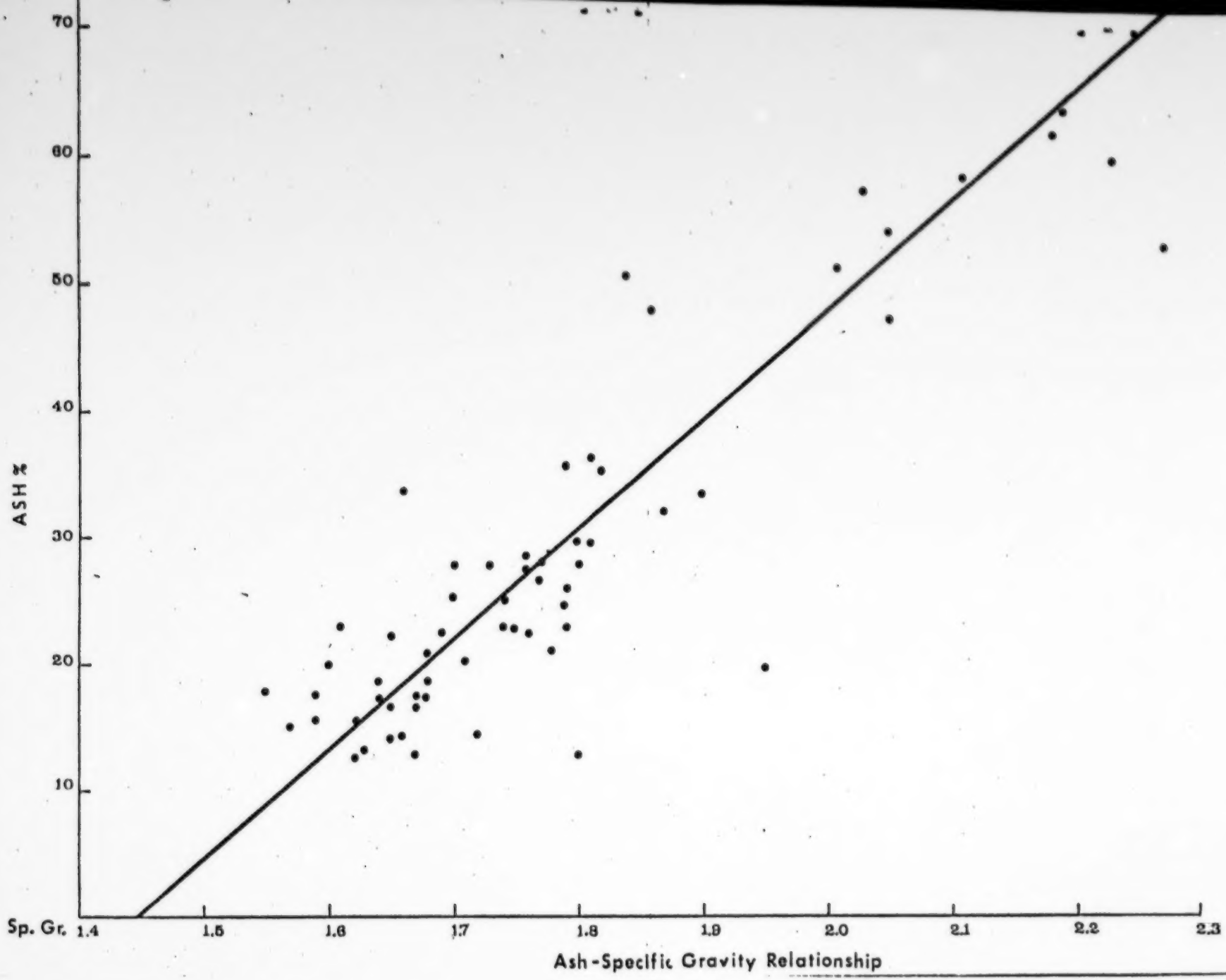


FIGURE 2. FLOW DIAGRAM FOR ANALYSIS





Ash-Equilibrium Moisture Relationship



Ash-Specific Gravity Relationship